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Velocity-Head Rod and Current Meter Use in Boulder-Strewn Mountain Streams

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The velocity-head rod should not be used in boulder-strewn mountain streams unless the gaged section can be modified to obtain uniform flow. The one-point current-meter method will suffice for most operational purposes.

Keywords: Velocity-head rod, current meter, flow velocities, flow velocity gradient, flow measurement methods, mountain streams.

Land managers concerned with investigations of water quality and yield, as well as other streamflow characteristics, need data on velocities and cross-sectional areas where stream-gaging stations do not exist. Rapidly changing flows in small mountain streams often demand quick surveys. Standard current-meter procedures are time consuming. A fast procedure such as provided by the velocity-head rod is therefore desirable. But questions arise about the accuracy of the rod as compared with that of the current meter in boulder-strewn streams.

The two devices were compared under field conditions on two streams of the Fraser Experimental Forest in central Colorado. Fool Creek was equipped with a San Dimas flume, while Deadhorse Creek had a 120° V-notch weir. The streams, described in detail elsewhere (Heede 1972), are typical of the alpine and subalpine zones of high mountains. The streambeds are armored by gravel and boulders. Flow regimens fluctuate between supercritical-turbulent and subcritical-turbulent. Sediment loads are extremely small in both streams; annual sediment yields vary from 22 to 88 pounds per acre (Leaf 1970).

The objective of this Note is not to discredit the velocity-head rod. The rod has its definite place under conditions different from those of our mountain streams. But it is the objective of this Note to warn the stream gager of pitfalls he may encounter under the stress of time and fund limitations when using either the velocity-head rod or current meter.

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Theory of Velocity-Head Rod

Wilm and Storey (1944), working at the San Dimas Experimental Forest, were credited with the development of the velocity-head rod (Linsley et al. 1949). The principle of the rod is based on Bernoulli's theorem that the absolute head of flow at any cross section is equal to the absolute head of flow at a section downstream plus intervening losses of head. After several assumptions, the basic equation becomes:

$$v_t = \sqrt{2gh} = 8.02 \sqrt{h}$$

where v_t is the theoretical velocity, g is the acceleration due to gravity, and h is the static head. This theoretical velocity is computed from the static head when the velocity-head rod is used.

The stream gager selects as solid a footing as possible for the rod, and turns the sharp edge of the rod upstream. Water surface elevation is read on the rod scale for the flow that occurs most frequently at the time of measurement. Then the rod is turned with its broad side upstream. The water impinges on the rod, signifying conversion of the kinetic energy of the flow to potential energy. The rod scale is read again for the most frequent elevation. Subtracting the first reading from the second yields h of the above equation: h is also called the velocity head and is expressed in feet. Tables exist to facilitate the velocity calculations (King 1954).

The computed velocity is, of course, an approximation. Wilm and Storey (1944) warn not to use the rod if velocities are much below 1 ft/s (foot per second) or above 8 ft/s, or if the channel bottom is soft. If velocities are much smaller than 1 ft/s, elevation differences caused by the velocity head may be so small that even approximate readings cannot be obtained. At velocities

above 8 ft/s, it is difficult to turn the rod from the edge to broad side upstream without losing the rod location on the streambed. The road location can also be lost easily in a soft stream bottom. The exact location must be kept for both rod readings, otherwise large errors may be introduced. Also if velocities increase above 8 ft/s, the slope of the energy gradient may steepen to such an extent that vertical components of flow may be introduced.

The theory summarized above is valid only for a prismatic channel and conditions of uniform flow so that the water surface is parallel to the channel bottom. As King (1954) proposes, however, the theory can be applied in most cases without material error, except for very steep slopes.

Velocity-Head Rod Measurements

A velocity-head rod, 5 ft high and 3 inches wide, was designed and built from aluminum. The prototype developed by Wilm and Storey (1944) served as the basis of the design. The light weight of the rod proved to be an asset.

We took velocity-head rod measurements when velocities of Fool Creek ranged between 1 and 8 ft/s; the majority were between 3 and 4 ft/s. The survey cross sections were between 3 and 6 ft wide, and the measurements were spaced across the stream at 0.5-ft intervals. Discharge calculations followed the centroid method applied in standard current-meter procedures.

The calculated discharges were compared with the simultaneous recordings of a San Dimas flume which gages the flow of Fool Creek. This flume, used also in other long-term research on the watershed, has a well established rating curve. Ratios between discharges derived from the velocity-head rod measurements and flume recordings were established. The overall mean ratio was 1.65 ± 0.08 with a confidence level of 0.95. It should be emphasized that these results are influenced by the cross sections surveyed, and are not necessarily representative of all mountain streams and situations.

The high losses of discharge between survey sections and flume could not be attributed to channel storage or deep seepage because the cross sections were close to the flume on a thoroughly studied stream. Data based on current-meter measurements, shown later, were on the average much closer to those of the flume.

Current-Meter Measurements

We used a Gurley No. 625 Pygmy current meter, attached to a wading rod, with the centroid method for velocity and discharge determinations. This meter is of the Price type. The vertical sections for point-velocity measurements were spaced 0.5 ft in all cross sections. Point velocities were taken at 0.2 and 0.8 depths wherever possible, otherwise one measurement at 0.6 depth was obtained.

Table 1 compares the discharge rates of Fool Creek, calculated from current meter measurements at five cross sections, with the instantaneous San Dimas flume recordings. Although the ratios of meter to flume data show considerable variation, ranging from 0.58 to 1.77, the majority were between 0.80 and 1.20. The mean ratio of all cross sections is 1.02 ± 0.06, with a confidence level of 0.95. Analysis of variance and multiple range ordering of the individual cross sections showed a significant difference between cross sections C and D only, indicating that one cross section is "out of tune" with others. Since a limited number of cross sections is represented here, the question of validity of results arises. The cross sections were selected to give a wide range of problems facing the stream gager using a head rod or current meter. It can be surmised, therefore, that other locations and cross sections most likely will show less variation.

Table 1.--Ratios of discharges derived from current meter readings to flume recordings, Fool Creek

Cross section	Sample size	Mean ratio	Standard error
A	16	1.18	0.37
B	10	1.01	.19
C	6	.97	.10
D	9	1.27	.15
E	10	.98	.13

Vertical Velocity Gradients

It is well known that, in highly turbulent mountain streams, the vertical velocity gradient does not have logarithmic profile, a characteristic often found in larger channels. But the extensive deviations from the "classic" profile are much less known. These deviations are illustrated by two characteristic profiles of Deadhorse Creek (figs. 1 and 2), based on measurements at depth spacings as close as permitted by the Pygmy current meter. The profiles indicate that nearly any shape of gradient could be found with the exception of two points; the point at zero depth must go through the point of origin and the point at the water surface will always have a velocity greater than zero.

Comparison of Standard Current-Meter Results with Extensively Measured Velocity Profiles

To evaluate the validity of standard current-meter procedures in mountain streams using the one- or two-point measurement techniques, we compared the average velocities obtained from such measurements with those

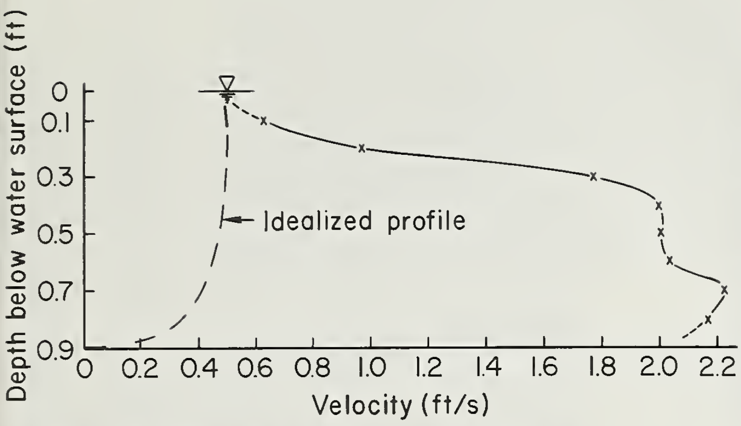

Figure 1. —The vertical velocity profile was measured with a Pygmy current meter during a discharge of 1.32 ft³/s at cross section B of Deadhorse Creek. Distance of vertical section from closest bank is 0.3 ft. The stage is slightly falling. The "classic" velocity distribution in streams is superimposed as an idealized profile.

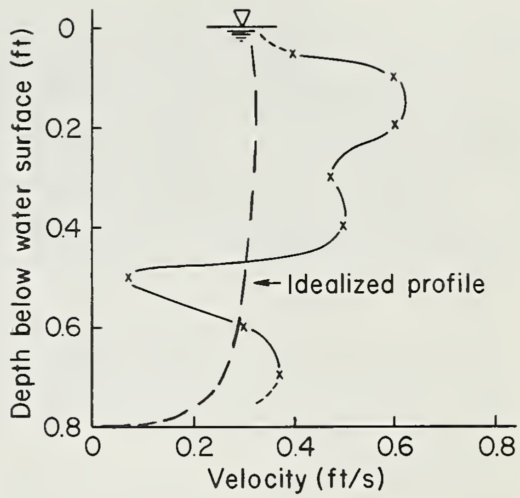

Figure 2.—The vertical velocity profile at cross section C of Deadhorse Creek during a discharge of 1.95 ft³/s. The stage is slightly falling. The vertical section is located 0.7 ft from the closest bank. An idealized profile, representing the "classic" velocity distribution in streams, is superimposed.

based on all measured points (table 2). Conventional depths below the water surface were used for the first two methods — 0.6 depth for the one-point and 0.2 and 0.8 depths for the two-point methods. When all measurable point velocities were taken in the vertical section, a very dense distribution was obtained and we felt justified, therefore, to read the 0.6-, 0.2-, and 0.8-point velocities from graphic depth profiles. This procedure eliminated a time lapse between measurements by different methods, and with it any possible changes in flow characteristics such as alterations of flow lines.

Statistical analysis indicated that the cross sections did not behave differently for either method, and the difference between the ratios of one- and two-point methods to all measured points was not significant (0.95 confidence level). This lack of difference is due, of course, to the wide variation in the individual readings (table 2), caused by the high turbulence of flow. Table 2 indicates also that total depth of flow less than 1 ft, such as encountered in this investigation, does not influence the accuracy of either method.

Discussion

Discharge rates calculated from velocity-head rod data were between 115 and 204 percent of those of the flume. It is postulated that, in part, the higher rod values reflect losses of elevation on the streambed when the rod was turned with its broad side upstream. Rounded gravel and boulders on the bed often provided a slippery footing for the rod, and under pressure of the impinging water, the rod moved from a high to a low point. Also, and possibly more influential, were rapidly changing, diverging flow lines (rotational flow) leading to "rooster tails" on each side of the rod, indicating incomplete conversion of velocity head to depth. These flow

Table 2.--Comparison of average velocities of a vertical stream section based on the ratios of 1- and 2-point methods to all measured points, Deadhorse Creek

Distance from nearest bank (Feet)	Total water depth (Feet)	Ratio between: 1-point / all points	2-point / all points
Cross Section B			
Discharge 1.32 ft³/sec			
0.30	0.90	1.17	0.88
.80	.77	.72	1.13
.90	.70	.59	1.01
.40	.42	.93	.80
Discharge 1.55 ft³/sec			
.30	.84	1.00	.94
.80	.75	.80	1.09
.90	.67	.82	1.24
.40	.42	.98	1.03
Cross Section C			
Discharge 1.95 ft³/sec			
.30	.75	1.55	.86
.80	.75	1.41	1.05
1.30	.90	1.17	1.12
.70	.80	.15	1.19
	Mean:	.94 ±.11	1.03 ±.04

line changes were caused by channel roughness due to coarse gravel, boulders, and rock outcrops. In our rough channels, cross-sectional areas determined by the centroid method were inaccurate and added to the deviations of the calculated data. Also, a degree of subjectivity is

added to the rod readings since determination of the water surface elevation that occurs most frequently during the time of observation is based on judgment.

Past experience has shown that velocity-head rod measurements are reliable within a few percent (Wilm and Storey 1944) if channel bottoms are relatively smooth and cross sections can be determined accurately such as in flumes or concrete channels. Under these conditions, changes of the water surface elevation are not erratic as in our mountain streams and the flow is irrotational. Goodell[2] found good agreement between flow input, as measured by a Venturi meter, to a long, uniform channel in the laboratory and discharge in the channel as measured by velocity-head rod.

Discharge rates obtained from the centroid current-meter method were much closer to those of the flume, and in contrast to the head-rod data, moved between minus and plus values relative to the flume. The current meter deviations are attributed to the impossibility of determining accurate cross sections of flow in a boulder-strewn stream, and to the rapidly changing flow lines (turbulent flow). We used meter periods of 1 minute under more severe conditions. Longer individual meter times would substantially increase the total survey time of a cross section, which in turn could introduce error due to changes in flow occurring within this time span. It took 25 to 30 minutes to survey our small mountain streams by current meter.

The large deviations of the vertical velocity profile from the classic logarithmic distribution are, of course, caused by the high turbulence of flow. Under such conditions, horizontal and vertical flow components may alternate by depth, resulting in drastic changes of velocities in the downstream direction. Velocity is a vector quantity because it possesses both magnitude and direction. Current meters do not respond equally to all directions of flow. The current meter used, with cups rotating around a vertical axis, reflects mainly velocities in the downstream direction, and does not record minus velocities caused by eddies. Yet, the average velocity of a section is the resultant of all individual velocities, regardless of direction. In terms of flow, discharge is the quantity of flow that passes a given cross section in a given period of time, regardless of the angle of passage. It follows that current meters do not record true velocities in turbulent streams (Yarnell and Nagler 1931).

The bizarre profiles of the vertical velocity gradients of flow led to wide variations in average calculations, whether the one-point or two-point method was used. Thus, at the 0.95 confidence level, neither method is superior.

[2]Personal communication from Dr. B. C. Goodell, retired, Rocky Mountain Forest and Range Experiment Station.

Conclusion

The velocity-head rod should be used if channel bottoms are fairly smooth, channels are approximately prismatic, and cross sections are close to plain geometric figures. The rod is an efficient tool for calibrating or checking calibration changes of a flume, and it could be useful in urban runoff investigations. It should not be used in boulder-strewn mountain streams carrying highly turbulent flows without first modifying the gaged section to obtain uniform flow conditions.

In boulder-strewn mountain streams where cross sections cannot be changed to facilitate velocity-head rod use, velocities should be obtained from current-meter readings. It should be recognized that rotational flow prevails in these streams, water surface elevations fluctuate erratically, and flow lines change rapidly, leading to bizarre vertical velocity profiles. Thus, wide variations in the individual readings are introduced, and it will suffice, therefore, for most operational purposes to use the one-point current meter method to save time. The majority of the individual readings will produce an error in discharge rates within ± 20 percent as compared with the flume, while errors in head-rod readings without channel modification will range between + 15 and + 104 percent. Although in this study the flume was assumed to yield true values, the error at the discharge rates experienced is about ± 5 percent.

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